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Giant fluctuations in complex fluids in microgravity and ground conditions

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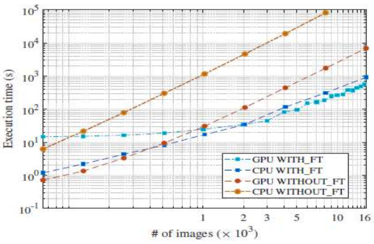
This work is part of ESA's Giant Fluctuation Space Project, also called Neuf-Dix project. It aims to study the phenomena governing non-equilibrium fluctuations (NEFs) in complex fluids and to develop new methods for the metrology of its transport properties. Fluctuations occur spontaneously in a fluid and are amplified by the presence of a gradient of, at least, one thermodynamic variable (concentration, temperature or pressure). The spatio-temporal evolution of NEFs, can be represented by the structure function of the Shadowgraph images over a wide range of wave numbers, as calculated by means of the differential dynamic algorithm (DDA) [1]. We will focus on the software development part.

Structure function computing

Depending on the number and size of the images, the computation times can be extremely long, limiting the applicability of this method in several practical cases.

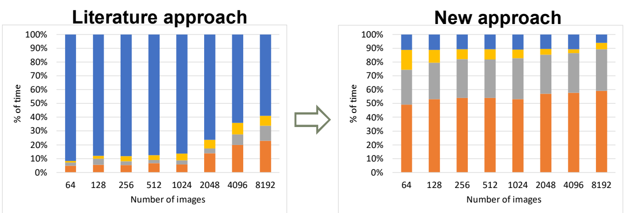


Execution time as a function of the total number of images for images of 512 × 512 pixels using different DDA programming approaches [1].

A remarkable increase in processing speed was achieved by using a new parallel development approach with GPU (Graphics Processing Unit).

DDA algorithm steps:

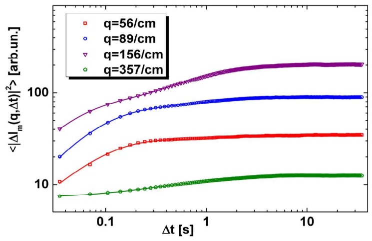
- Reading from disk
- FFTs computing
- CPU-GPU Exchanging
- FFTs differences and averages



Our new approach is between 6 and 12 times faster than the fastest approach of the literature.

Structure function analysis

At each wave number, the structure function can be analyzed after providing a theoretical model (fitting equation) in order to extract the amplitudes and the dynamics of the fluctuations. The applicable model varies depending on the nature and conditions of the experiment, which can be a real challenge for the analysis of large amount of data.



The structure function as a function of the correlation time for different wave numbers. We notice that its shape can change from one wave number to another, so that the theoretical model also changes.

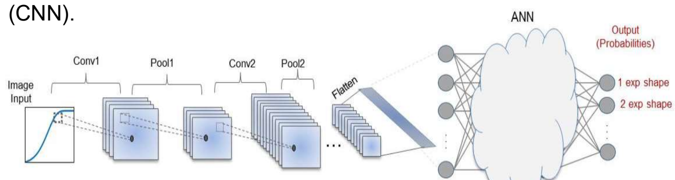
Theoretical model [2]:

$$\langle|\Delta I_m(q,t)|^2\rangle = 2\{T(q)I_s(q)[1-\boxed{ISF(q,t)}]+\boxed{BG(q)}\}$$

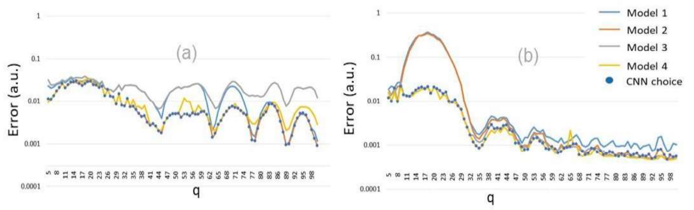
$T(q)$: Shadowgraph transfer function
$I_s(q)$: Averaged scattered intensity
$ISF(q,t)$: Scattered intermediary function
$BG(q)$: background

Can have different forms

An automatic analysis of the structure function is possible using the Artificial Intelligence (AI), exactly the Convolutional Neural Netwoks (CNN).



Analysis of Two experimental structure functions. (a) for TEG-water binary mixture and (b) for PS-Toluene mixture.



The fitting equation that has the smallest error is chosen in almost all wave numbers.

Conclusion:

- ✓ We have developed a new method of programming the structure function based on parallelization techniques on graphic cards (GPUs) that allows to drastically reduce the computation time.
- ✓ We have developed a program based on neural networks that predicts the best model to fit the structure function at each wave number.

The combination of the two programs allows to compute the structure function in quasi-real time and to extract the amplitudes and dynamics of the fluctuations in an automatic way.

References:

[1] M. Norouzisadeh, M. Chraga, G. Cerchiari, and F. Croccolo, “The modern structurator: increased performance for calculating the structure function,” *Eur. Phys. J. E*, vol. 44, no. 12, p. 146, Dec. 2021.
[2] F. Croccolo, D. Brogioli, A. Vailati, M. Giglio, and D. S. Cannell, “Nondiffusive decay of gradient-driven fluctuations in a free-diffusion process,” *Phys. Rev. E*, vol. 76, no. 4, p. 041112, Oct. 2007.